ON BONDING REPAIRING STEEL FIBRE REINFORCED CONCRETE TO HARDENED CONCRETE

ABSTRACT: In the last years an emerging repair and strengthening technique for concrete slabs has been used, consisting of applying a thin layer of steel fibre reinforced concrete (SFRC) onto the existent concrete slab. The performance of the structural system depends on the bonding behaviour between old and new concretes. Adhesives based on epoxy resins currently make this liaison. The prices of these adhesives are quite different depending, mainly, on the percentage of pure resin that they include. In the present paper, three commercial adhesive compounds of distinct prices and properties were selected to bond concrete base and repairing SFRC overlay. The bond behaviour was assessed from pull-off tests and the influence of the strength class of concrete base and repairing SFRC was analysed. Finally, the performance of the adhesives was evaluated, considering both the bond strength and their prices.

Keywords: pull-off test, epoxy adhesive, thin-bonded overlay, steel fibre reinforced concrete.

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INTRODUCTION

Thin overlays repair made of cementitious materials, resinous materials and polymer-modified cementitious materials are being used for strengthening and rehabilitation purposes in concrete pavements, concrete bridges and asphalt pavements [1-4]. Due to the enhanced properties of steel fibre reinforced concrete (SFRC), such as ductility under compression and high flexural toughness, it is expected that SFRC is advantageous in those applications.

The epoxy resins are widely used as bond products for most materials used in construction, such as concrete, masonry units, wood, glass, and metals. Epoxy-based resins are also good adhesives to bond fresh to hardened concrete, and bonding fresh concrete overlay to an existing slab is an example of such application [5]. The development and maintenance of a sound bond between the overlay and the existing concrete substrate is an utmost requirement for the performance of the strengthening purpose. By the way, epoxide adhesives guarantee sufficient adhesion, enabling the strengthened structure to behave monolithically in resisting loading and curling stresses [2-4].

The present work deals with the bond between SFRC overlay and concrete substrate, and is a part of a more comprehensive work, which aims at evaluating the structural performance of thin bonded SFRC in the strengthening and rehabilitation of laminar structures.

This paper presents and analyzes the results of an experimental research program aiming at investigating the effect of the strength class of the concrete substrate and the concrete overlay on the adhesion performance between these materials. The profitability of three commercially available bond products was also assessed. The experimental program was composed by three test groups, each one of distinct concrete strength class for the substrate. Each group is constituted by two series of different concrete strength classes for the overlay. To avoid the tendency of the failure at the lower strength class of the substrate, a maximum difference of one strength class was adopted for the concrete of the overlay and the substrate. The concrete overlay was always reinforced with steel fibres. Further details regarding the present study can be found elsewhere [6].

MATERIALS AND TEST SET-UP

Concrete Substrate and SFRC Overlay

Three compressive strength grades for the concrete base, according to [7], were established: C20/30, C40/50, C60/70; and six compressive strength grades for the concrete layer reinforced with steel fibres (SFRC): C20/30, C30/40, C40/50, C50/60, C60/70 and C65/75. For the purpose of defining the mix properties, the Faury mix design method was used, see e.g. [8], together with aggregates available in the Northern Region of Portugal (Minho). Hooked ends DRAMIX® RC-80/60-BN steel fibres [9] were used to reinforce the concrete overlay. In previous work it was verified that this fibre has high performance since significant increase in the ultimate load bearing capacity of the structural concrete elements was obtained [10]. Table 1 shows the average compressive strength of the ordinary concrete (substrate) and SFRC overlay achieved from 3 cylinder specimens (150 mm x 300 mm) at 28 days of age. C1 to C6 refers to concrete overlay used for bond coat applied on dry substrate surface. And C1’ to C5’ refers to concrete overlay used for bond coat applied on saturated substrate.

Table 1 Concrete base and SFRC overlay compressive strength (in MPa).

<table>
<tr><td rowspan="2">BASE
(plain concrete)</td><td colspan="2">B1</td><td colspan="2">B2</td><td colspan="2">B3</td></tr>
<tr><td colspan="2">22.32</td><td colspan="2">42.59</td><td colspan="2">60.82</td></tr>
<tr><td rowspan="4">OVERLAY
(SFRC)</td><td>C1</td><td>C2</td><td>C3</td><td>C4</td><td>C5</td><td>C6</td></tr>
<tr><td>25.87</td><td>32.08</td><td>41.50</td><td>53.51</td><td>62.54</td><td>66.81</td></tr>
<tr><td>C1’</td><td>C2’</td><td>C3’</td><td>C4’</td><td colspan="2">C5’</td></tr>
<tr><td>27.36</td><td>38.48</td><td>58.46</td><td>66.67</td><td colspan="2">61.78</td></tr>
</table>

Bond Products

Three types of epoxy-based bond agents were selected to bond fresh SFRC overlay to hardened concrete substrate, namely two epoxy resin-based products (P1 and P2), and one epoxy resin and cement-based product (P3). Table 2 shows some summarized information about the bond products. The P1 and P2 coating materials were applied onto dry and clean, i.e., free from surface contaminants such as dust, laitance, oil or grease, according with the manufacturer [11]. To evaluate the influence of the surface conditions on the bond coat material, P3 was applied onto two types of substrate surface: dry surface and saturated surface.

Table 2 Data extracted from commercial datasheet for the bond products [11].

BOND	**BRIEF DESCRIPTION**	**BOND STRENGTH**	**MECHANICAL RESISTANCE**
P1	Epoxy resin-base bond coat, free from solvents, available in 2 components.	to concrete: ~3 MPa (concrete failure) to sandblasted steel: ~20 MPa	Compressive strength: ~90 MPa Flexural strength: ~45 MPa
P2	Epoxy resins-base bond coat available in 2 components, free from solvents.	to concrete: 2.5 - 3.0 MPa (concrete failure) to steel:	Compressive strength: ~60 - 70 MPa Tensile strength: ~18 - 20 MPa
P3	Anticorrosive coating and adhesive agent cement and modified epoxy resin-base, available in 3 components.	to sandblasted concrete: 2 - 3 MPa to steel: 1 - 2 MPa	-

Preparation of the Specimens

Nonreinforced concrete slabs of 300 mm x 650 mm, with 80 mm thickness, were used as concrete substrate. When the concrete substrate attained 28 days of age, the top surface of the slab specimen was treated. The bond product was then applied and the fresh concrete overlay was cast. The work of bonding the fresh SFRC overlay to the hardened concrete followed the manufactures specifications [11] and the ACI guidelines [12-14]. For the aims of this research, an overlay thickness of ~30 mm of SFRC layer was adopted. Figure 1 shows a specimen before surface treatment and the equipment used to rough the surface. The process of roughing the top surface of the concrete substrate had the purpose of removing a very thin layer of the surface, in order to remove grease, oils, free particles, laitance or dirt, as well as producing an irregular surface. Figure 2 shows the main bond steps. When the concrete overlay attained an age of about 28 days, the partial core was drilled and the pull-off tests were carried out.


(a) (b)

Figure 1 The top surface of one specimen before roughing (a) and the rough machine (b).

It is stressed that a mini slipform paver, Figure 2 (g), was used to consolidate the SFRC overlay. The mini slipform simulates the real conditions of compaction of thin SFRC overlay.

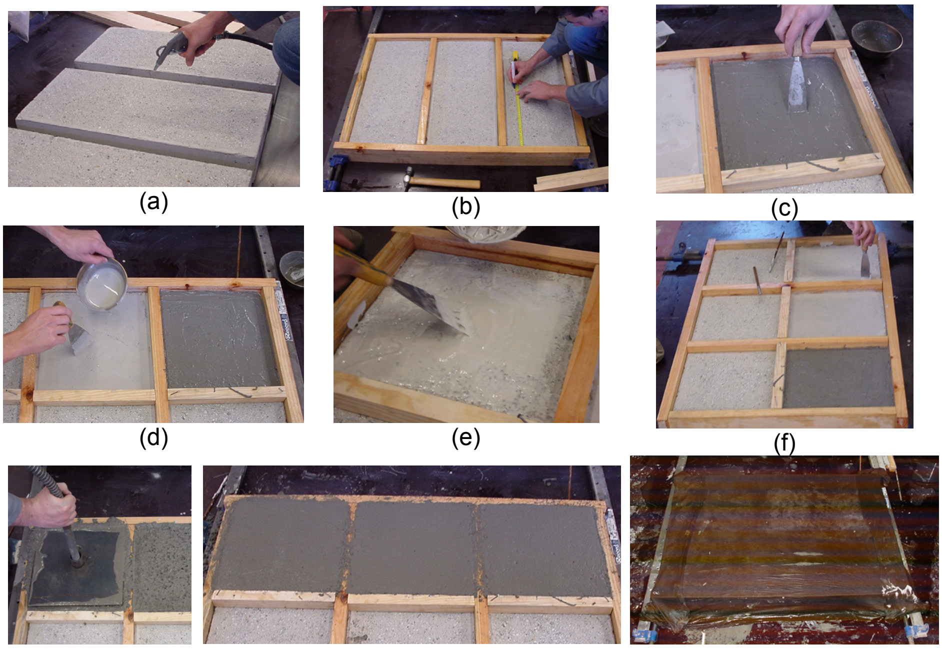

(a) (b) (c)
(d) (e) (f)
(g) (h) (i)

Figure 2 Main steps of the bond process of the SFRC overlay: (a) cleaning the top surface with compressed air jet, (b) definition of the area for each bond coat material, (c) placing the bond product P3, (d) placing the bond product P2, (e) placing the bond product P1, (f) overview of the bond coats before casting the fresh SFRC overlay, (g) consolidating of the SFRC, (h) final aspect of the finished surface, and (i) curing with wet burlap.

Pull-off Test Equipment

One of the devices evaluated in the study [3] includes the test equipment chosen for the present work, namely Proceq DYNA Z15, with 48 mm diameter disc. This equipment has load capacity of 16 kN, accuracy < 2% and resolution of 0.10 MPa [19]. In [16-20] the general procedures of carrying out the pull-off tests are described. After performing the test, the failure mode was carefully analysed to provide information about what was really measured. In this work a core diameter of 48 mm with approximately 15±5 mm of drilling depth into the substrate was adopted. The loading rate was settled for the tests closely

0.05±0.01 MPa s^{-1}. These are common values adopted and suggested, for example, by [2,3,18,19].

RESULTS

The average pull-off strength values of four tests for all series are depicted in Figure 3. It can be seen that increasing the strength of the overlay does not lead to an increase of the pull-off strength. On the contrary, the strength of the substrate plays a major role in the pull-off strength. From the experimental data it is also possible to observe that the pull-off strength for bond product P3 is relatively low in comparison with the results for P1 and P2, meaning that the bond product plays a role in the response. The P2 bond material attained greater average pull-off strengths than the others bond materials, independently of the substrate and overlay compressive strength, see Figure 4. Figure 5 indicates linear increasing trend of pull-off strength with the compressive strength of concrete substrate and SFRC overlay.

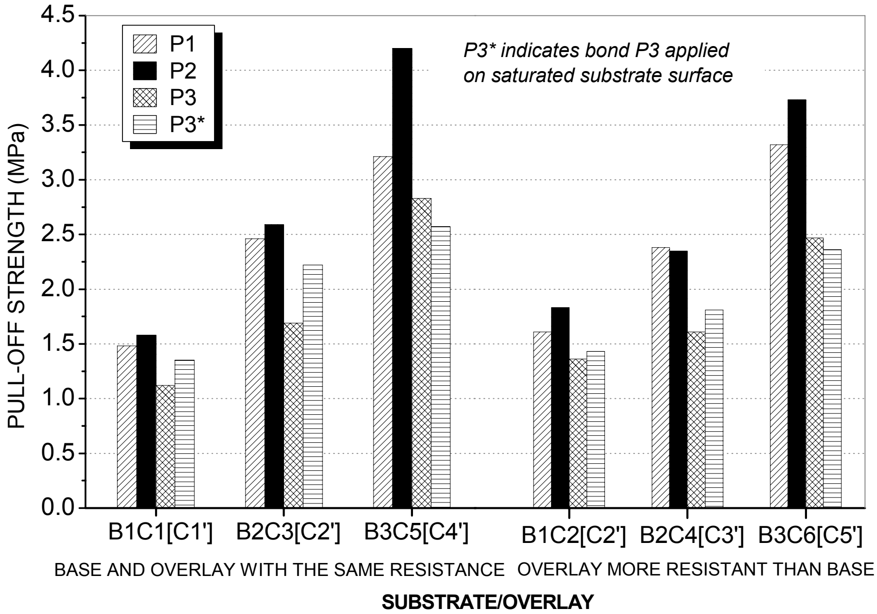
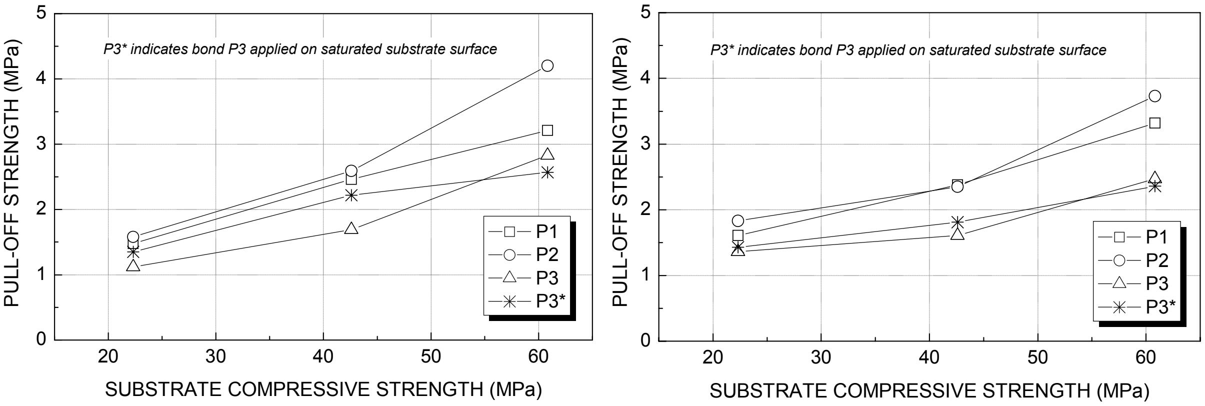


Figure 3 Pull-off average strength for each substrate and overlay type.

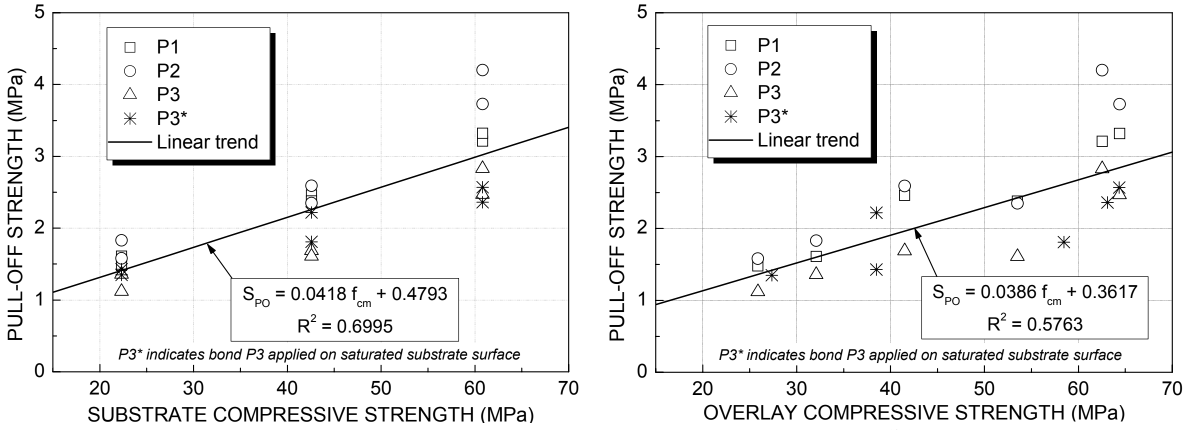


(a) (b)

Figure 4 SFRC overlay and concrete substrate with similar compressive strength (a), and SFRC overlay more resistant than the concrete base (b).

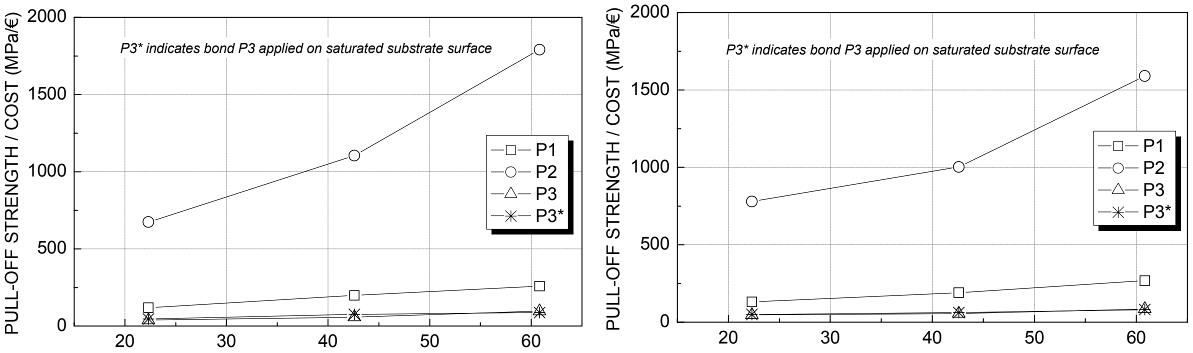
A marginal benefit is verified when the bond coat product P3 is applied on saturated substrate surface for the cases of low and medium concrete class strength of the base (models B1C1', B1C2', B2C2' and B2C3'). For the case of high concrete class strength of the base (models B3C4' and B3C5'), a reduction in the pull-off strength was observed (Figures 3 and 4). The substrate of these series was made by the highest concrete strength class. This type of concrete has offered higher resistance to the penetration of the water used to saturate the substrate surface, resulting in the formation of a water film that has decreased the bond strength between the two concrete materials.

The performance / cost comparison analyses based on average pull-off strength demonstrate that the average pull-off strength obtained with bond material P2 is 1.11 and 1.46 (1.36) times higher than the average pull-off strength obtained with P1 and P3 (and P3 with saturated substrate surface) bond materials, respectively. It is also verified that, increasing the substrate strength the ratio of strength to cost is increased for the three bond agents, meaning that the substrate plays a key role in the response. For the stronger substrate, the performance is twice the value registered in the weak substrate. The better strength to cost ratio was obtained for the bond coat material P2, independently of the substrate and overlay compressive strength (Figure 6).



(a) (b)

Figure 5 Effect of substrate strength (a), and overlay strength (b), on the pull-off strength.



(a) (b)

Figure 6 Comparison of performance to cost ratio for (a) SFRC overlay and concrete substrate with similar compressive strength, and (b) SFRC overlay more resistant than the concrete base.

SUMARY AND CONCLUSIONS

The conclusions from this experimental study are the following:

In general, all series have showed a large scatter in the pull-off tensile strength. Although this scatter, all bond coat materials exhibited average pull-off strength higher than 1.12 MPa. For the concrete substrate of low and medium strength class, bonded by P1 or P2 adhesives, there was a clear tendency for failing by the concrete substrate failure, which indicates that, in these cases, the base concrete was generally the weakest link in the repair system. In this way, the pull-off strength reflects the tensile strength of the concrete substrate;

For P1 and P2 bond materials the thin fibre reinforced concrete overlay was well bonded to the concrete substrate, and the tensile strength of the overlay has exceeded the tensile strength of the concrete substrate. Evidence of voids and non-uniform steel fibres distribution was observed in some failure surfaces, suggesting that, additional attention should be given to the consolidating procedures of the fibre reinforced concrete mixture;

The shape, maximum diameter and strength of coarse aggregates seem to have an important role in the pull-off strength, as for substrate of low / medium strength the crack surface was developed at the interface coarse aggregate-cement paste, while at substrates of high concrete strength the coarse aggregate was also crossed by the failure surface;

In general, the failure surface was located at top of the substrate concrete, just below the bond adhesive. The lower resistance of the top surface of the substrate might explain this behaviour. The procedure adopted in the preparation of this zone might have been responsible for part of this weakness;

The bond product P2 provided the highest pull-off strength values and, was the more economical, being the best bond product for this type of application.

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